Limits on the Magnetic Moment of the W Boson at the Collider Detector at Fermilab (CDF)

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ABSTRACT

Recently we obtained bounds on the magnetic moment of the W boson from preliminary results from CDF. These results were based on 4.3 pb^{-1} of data, from which were found 3 $W\gamma$ events and 3 radiative W decays. Within the next 2 years they expect to have almost 100 pb^{-1} of data. In this paper we consider the bounds one will be able to obtain from this data, under 2 scenarios:

(1) The expected Standard Model (SM) results are obtained.

(2) The relative number of events observed is the same as in the previous run. It is shown that scenario (2) leads to a clear breakdown of the SM.

In a recent letter[1] we showed how the preliminary results for $W\gamma$ production and radiative W decay from CDF[2] could be used to put bounds on the magnetic moment of the W boson, given by

$$\mu = (K + 1)e/2M_W \tag{1}$$

where the SM value is

$$K = 1, \ \mu = e/M_W \tag{2}$$

The best way to measure K is to make use of the radiation amplitude zero[3] (RAZ) which occurs in the angular distribution for $\bar{d}u \to W^-\gamma \, (u\bar{d} \to W^+\gamma)$ The dip which persists in $p\bar{p} \to W\gamma X$ is very sensitive to the magnetic moment parameter K. A similar zero occurs in the energy distribution of the radiative decay[4] $W^- \to \bar{d}u\gamma$ and $W^- \to e\bar{\nu}\gamma$. Because the number of events will still be limited it may still not yet be possible to make use of the RAZ.

In this paper we consider the bounds which one will be able to obtain from the total number of $W\gamma$ events and radiative decays from the next run of CDF, when they will have 20 times more integrated luminosity, under 2 scenarios:

(1) The expected SM results are obtained.

(2) The relative number of events is the same as in the previous run. ie They will obtain 20 times more $W\gamma$ events and 20 times more W radiative decays.

We consider (1) first and use the same cuts, experimental acceptances and efficiencies as in ref (1). Our result for the number of $W\gamma$ events is

$$n = 29.8 - .546\eta + 1.294\eta^2 \tag{3}$$

where η = K-1. For 20% systematic error at 95% C.L. we obtain the bound

$$-2.0 \leq K \leq 4.4 \tag{4}$$

while for 95% C.L. and 10% systematic error we get

$$-1.6 \leq K \leq 4.0 \tag{5}$$

These results are shown in Figure 1. For radiative W decays the number of events is given by

$$n = 155.8 + .630\eta + .894\eta^2 \tag{6}$$

For 95% C.L. and 20% systematic error the bound attainable will be

$$-7.2 \leq K \leq 8.5 \tag{7}$$

while for 95% C.L. and 10% systematic error it is

$$-5.4 \leq K \leq 6.7 \tag{8}$$

These results are shown in Figure 2. If we do not separate the $W\gamma$ events and the radiative W decays, the total number of events is given by

$$n = 185.6 + .0840\eta + 2.188\eta^2 \tag{9}$$

For 95% C.L. and 20% systematic errors we can obtain the bound

$$-4.5 \leq K \leq 6.4 \tag{10}$$

while for 10% systematic error and 95% C.L. it is

$$-3.2 \leq K \leq 5.1 \tag{11}$$

These results are shown in Figure 3.

We now turn to scenario (2). Here we consider the situation if CDF will measure 20 times the number of events measured in the first run. ie The number of W gamma events is for 20% systematic error is

$$n = 60 \pm 14.3 \tag{12}$$

so that n < 83.5 at 95% C.L. Using the result given in eq (3) the bound is

$$-5.2 \leq K \leq 7.7 \tag{13}$$

while for 10% systematic errors it is

$$-4.8 \leq K \leq 7.2 \tag{14}$$

at 95% C.L. These results are shown in Figure 1.

Now we come to the main point of this paper which we would like to emphasize. For radiative W decays the theoretical SM value is

$$n_{th} = 155.8 \tag{15}$$

Under this scenario, the number measured is $n_{exp} = 60 \pm 14.3$ for 20% systematic errors. Thus,

$$\Delta = n_{th} - n_{exp} = 95.8 \pm 14.3 \tag{16}$$

and there is a 6.7σ breakdown of the SM. Note here that there is no solution for K, as $n_{exp} < n_{th}$, and, thus, this would imply some further breakdown of the SM $\lambda \neq 0$. See ref (5).

For a 10% systematic error

$$n_{exp} = 60 \pm 9.8 \tag{17}$$

and $\Delta = 95.8 \pm 9.8$ and there is a 9.8σ breakdown of the SM. Again there is no solution for K.

Figure 4 shows these results for radiative W decay with and without the QCD corrections.[6] It can be seen that under scenario (2) there is a huge breakdown of the SM. The QCD corrections for Wγ are very small.

If we now consider the total number of events as before, by adding the total number of Wγ events and radiative W. decays, for 20% systematic errors we get

$$n_{exp} = 120 \pm 26.4 \tag{18}$$

$$\textit{and} \quad \Delta = 65.6 \pm 26.4 \tag{19}$$

and only a 2.5σ effect. For 10% systematic errors the result is

$$\Delta = 65.6 \pm 16.3 \tag{20}$$

a 4.0σ effect. These results are shown in Figure 5.

In conclusion we have shown that in about 2 years when CDF has 20 times more integrated luminosity we will be able to obtain some good bounds if the SM values are measured the best of which are

$$-2.0 \le K \le 4.4 \quad (95\% \textit{ C.L. and } 20\% \textit{ systematic}) \tag{21}$$

$$\textit{and } -1.6 \le K \le 4.0 \quad (95\% \textit{ C.L. and } 10\% \textit{ systematic}) \tag{22}$$

But the main point of the paper is to emphasize that if the number of events measured is merely

20 times the preliminary results there will be a strong breakdown of the SM at the $9.8\sigma(6.7\sigma)$ level for 10% (20%) systematic errors.

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References:

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Figure Captions

Figure 1: Number of events vs K for $W\gamma$. The line at 43.1 (40.1) corresponds to 95% C.L. and 20% (10%) systematic error for scenario (1) while the line at 83.5 (76.1) corresponds to 95% C.L. and 20% (10%) systematic error for scenario (2).

Figure 2: Number of events vs K for radiative W decay. The line at 210.9 (188.6) corresponds to 95% C.L. and 20% (10%) systematic error for scenario (1).

Figure 3: Number of events vs K for the sum of $W\gamma$ events and radiative W decay. The line at 250.4 (223.4) corresponds to 95% C.L. and 20% (10%) systematic error for scenario (1).

Figure 4: Number of events for radiative W decay vs K for the tree-level (QCD corrected) result is shown by solid (dashed) curve under scenario (2). The measured result for 20% (10%) systematic error is shown by the point with the large (small) error bars.

Figure 5: Number of events for the sum of $W\gamma$ events and radiative W decay. The measured result for 20% (10%) systematic error is shown by the point with large (small) error bars.

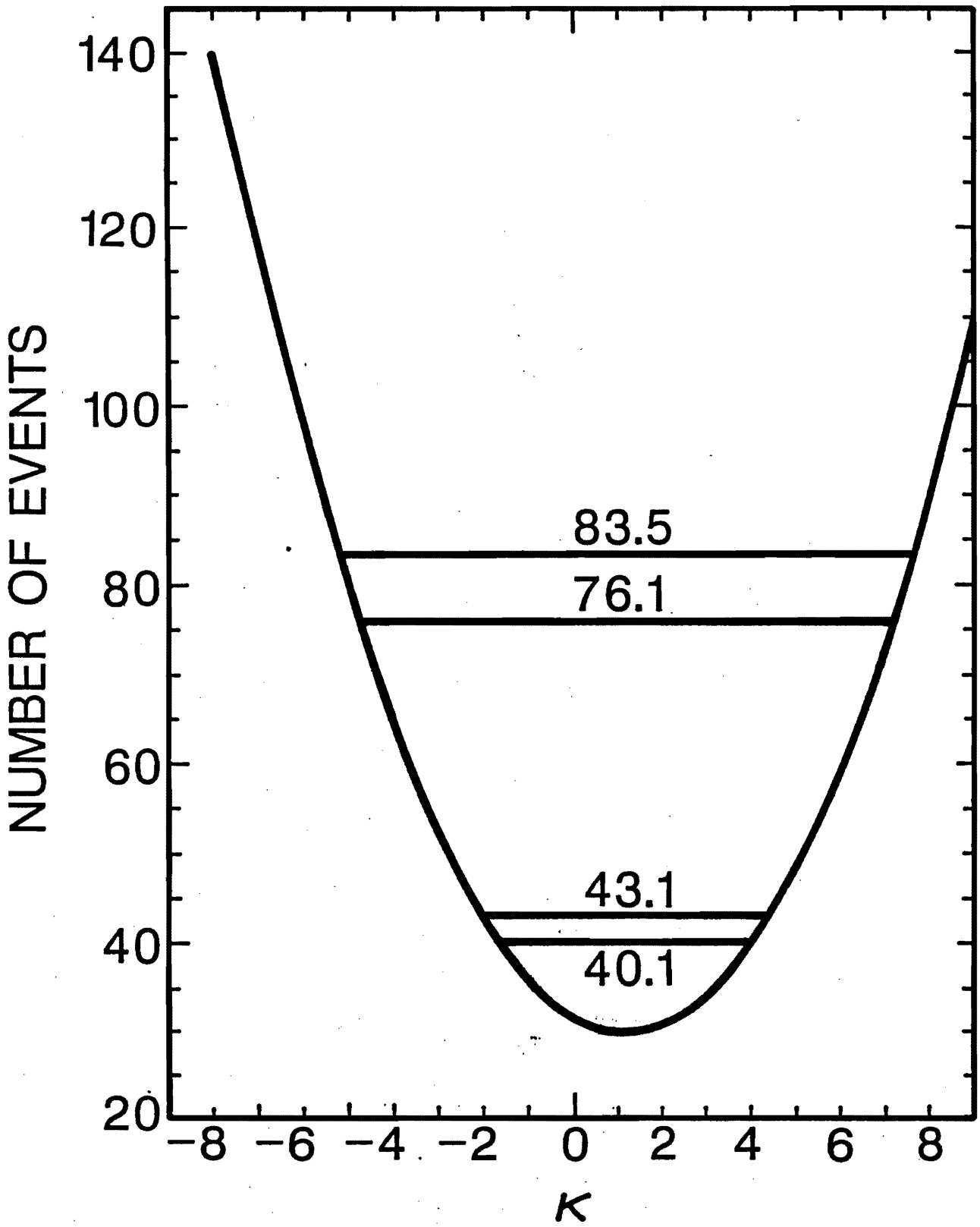
NUMBER OF EVENTS
140
120
100
80
60
40
20
83.5
76.1
43.1
40.1
−8
−6
−4
−2
0
2
4
6
8
κ

Figure 1

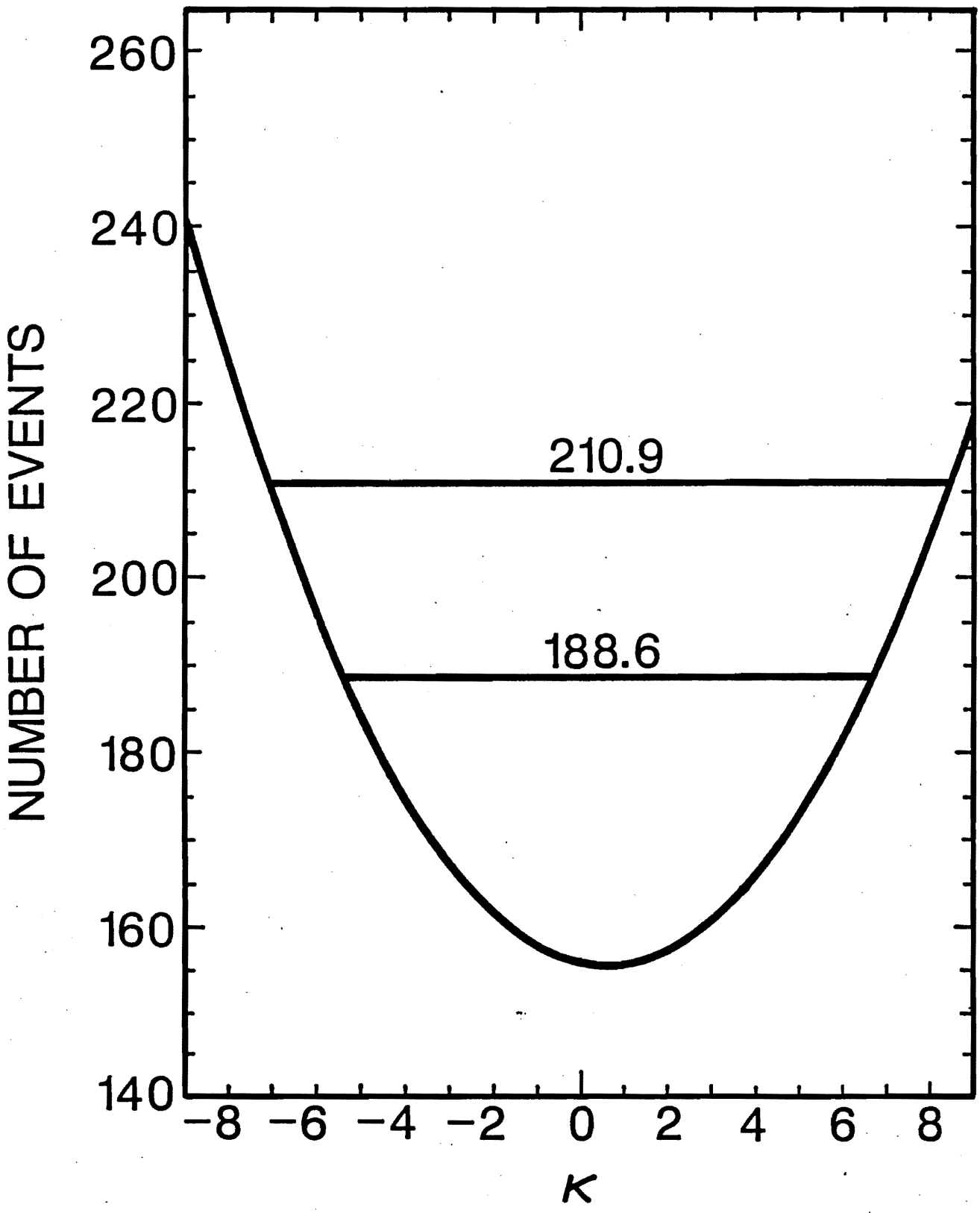
260
240
220
200
180
160
140
NUMBER OF EVENTS
210.9
188.6
−8
−6
−4
−2
0
2
4
6
8
κ

Figure 2

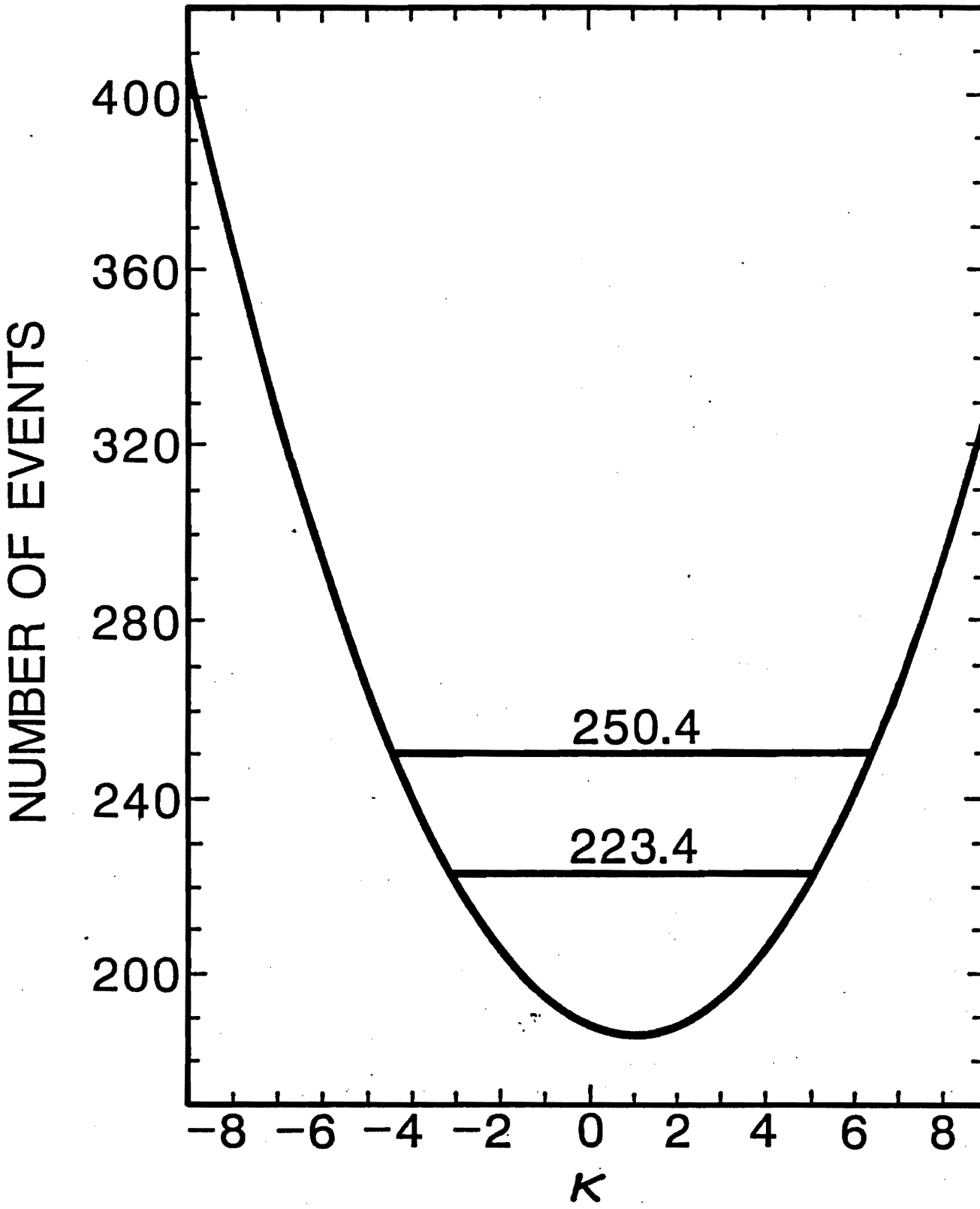
NUMBER OF EVENTS
400
360
320
280
240
200
250.4
223.4
−8
−6
−4
−2
0
2
4
6
8
κ

Figure 3

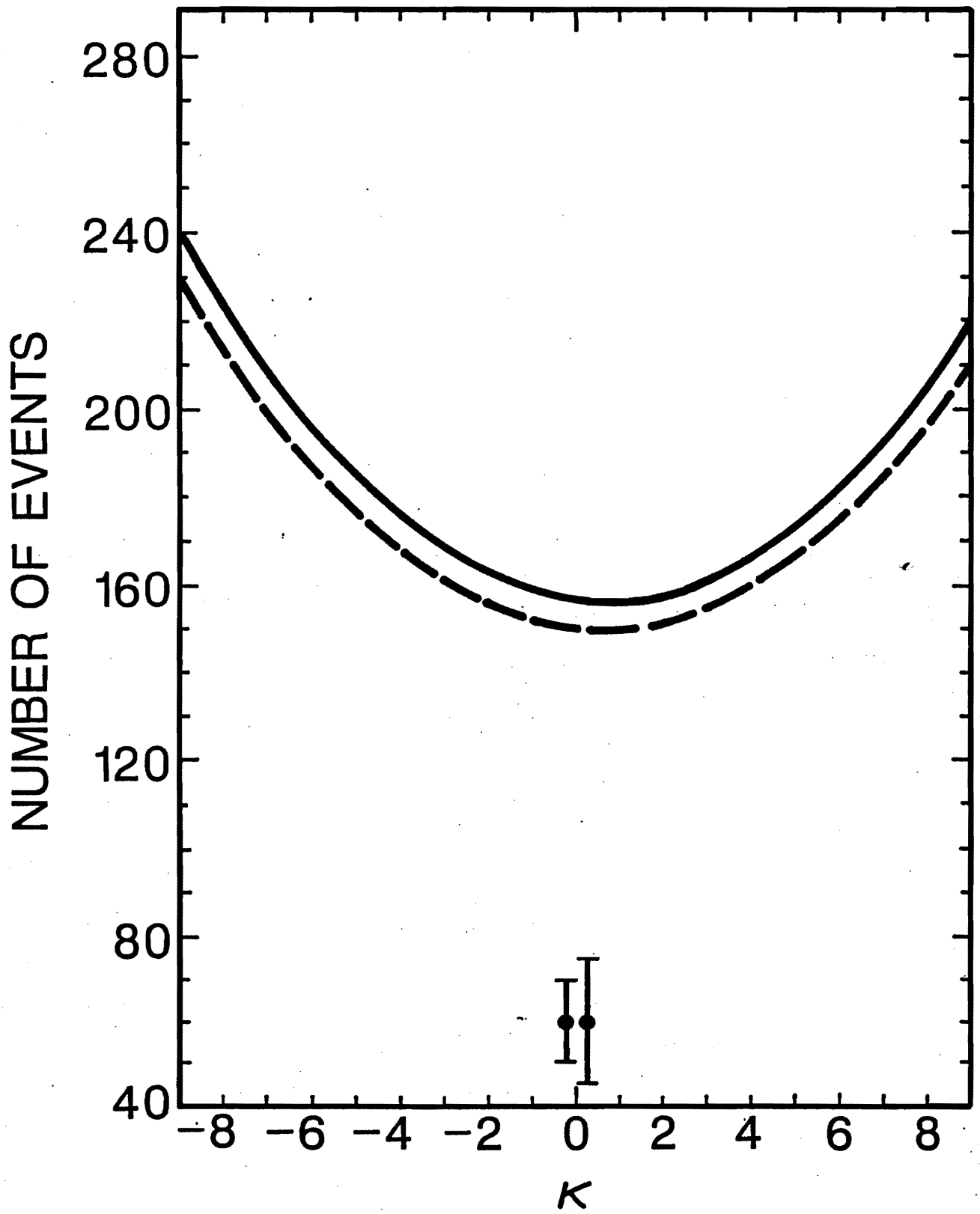

Figure 4

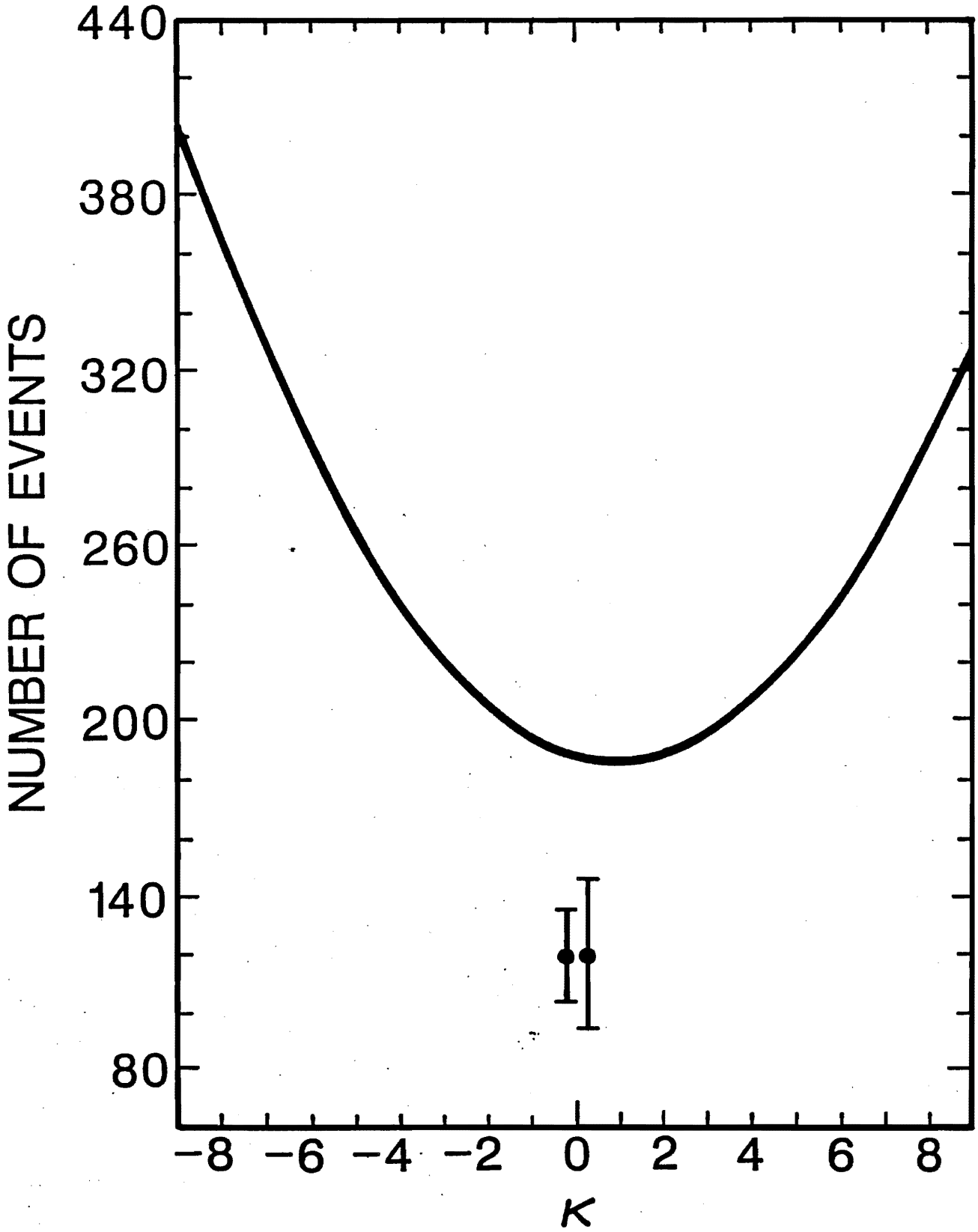

Figure 5